LA-UR-20-23556
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Title: Gigatonne One

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Intended for: Presentation to sponsors

Issued: 2020-05-13

Gigatonne One

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May 14th, 2020

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GIGATONNE ONE
EERE-BETO

Pitch:

- BECCS—CCS with biofuels, biopower, biomaterials—is key for clean energy-industry futures & for BETO.
- Need to understand spatio-temporal evolution of BECCS sources, sinks, & transportation.
- Massive-scale BECCS only happens within larger CCS system (*Gigatonne One*).
- **BECCS FOCUS:** leverage existing CCS data & tools when possible.

Tasks:

1. Tool to address national-level [BE]CCS futures/scenarios.
2. Ensemble capability for 100s of CCS pathways, 1000s of runs.
3. BECCS technology analysis.

Deliverable

- **ROADMAP:** Multi-path spatio-temporal BECCS strategy.

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Gigatonne One: CCS Roadmap for BECCS

Richard Middleton, EES-16 (Los Alamos National Lab)

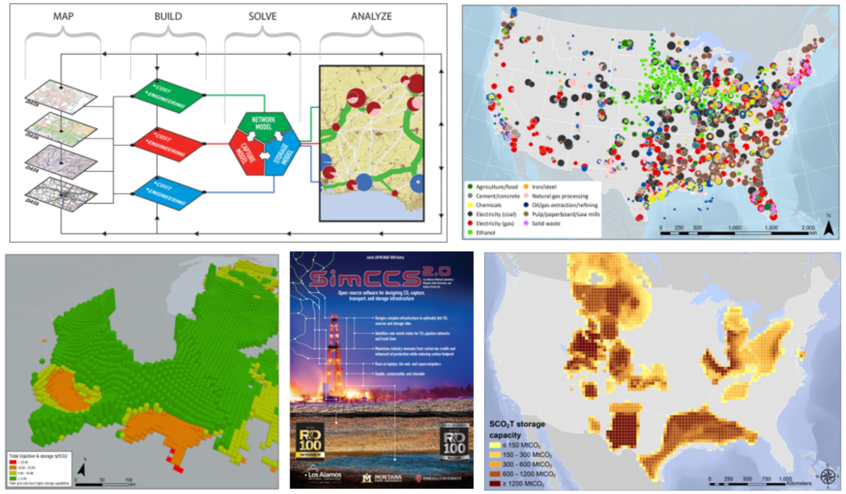
Overview

Objective: Multi-scenario roadmap for national-scale BECCS (bioenergy with CO_2 capture & storage)—ethanol, biopower, biomaterials (e.g., paper/pulpboard)—based on emerging tools, bioeconomy, & thousands of simulations.

Description of Effort: Nation-wide CCS infrastructure using *SimCCS* framework (including CO_2 storage through *SCO_2T*). Build (1) BECCS-only scenarios & (2) BECCS integrated with projected nationwide CCS (i.e., Project *Gigatonne One*).

LANL Unique Capabilities Leveraged: Unique, R&D 100 Award physics-based tools: (1) *SimCCS* realistically deploy CCS infrastructure based on economics & engineering, perform 1000s of realizations; (2) *SCO_2T* physics-based estimation of national-scale storage capacities & costs (critical for BECCS).

Graphical Abstract and Preliminary Results



Impact

Benefits: Key innovation leaps: (1) Multiple scenarios (1000s) based on policy, economics, LCA, & uncertainty; (2) integrated CO_2-bioeconomy analysis (biofuels/power/materials); (3) driven by realistic CO_2 storage (only at LANL); (4) integrated with emerging CO_2-based economy; (5) emerging machine-learning. *SimCCS*/*SCO_2T* already industry leaders.

Challenges:

- Scale-up in domain size, solution times, & ensemble analysis.
- Machine learning to process 1000s of scenarios.
- Developing BETO-related CO_2 emissions & scenarios.

Maturity of Technology: Current: TRL 4/5. End : TRL 6. Effort focused on data/scenario evolution & technology development.

Action Plan and Expected Outcomes

Major Goals and Milestones by Fiscal Year:

- Enhanced captuable-CO_2 database focused on BETO (Yr 1).
- Capture tech. assessment, biopower projection (Yr 1).
- Enhanced *SCO_2T* database for BECCS (Yr 2).
- Multi-scenario *SimCCS* framework approach (Yr 2).
- Major deliverable: BECCS multi-scenario roadmap (Yr 3).

Proposed Funding ($k): $1050k

- Year 1: $300k (LANL), $50k (ORNL).
- Year 2: $300k (LANL), $50k (ORNL).
- Year 3: $300k (LANL), $50k (ORNL).

Period of Performance (months): 36 months.

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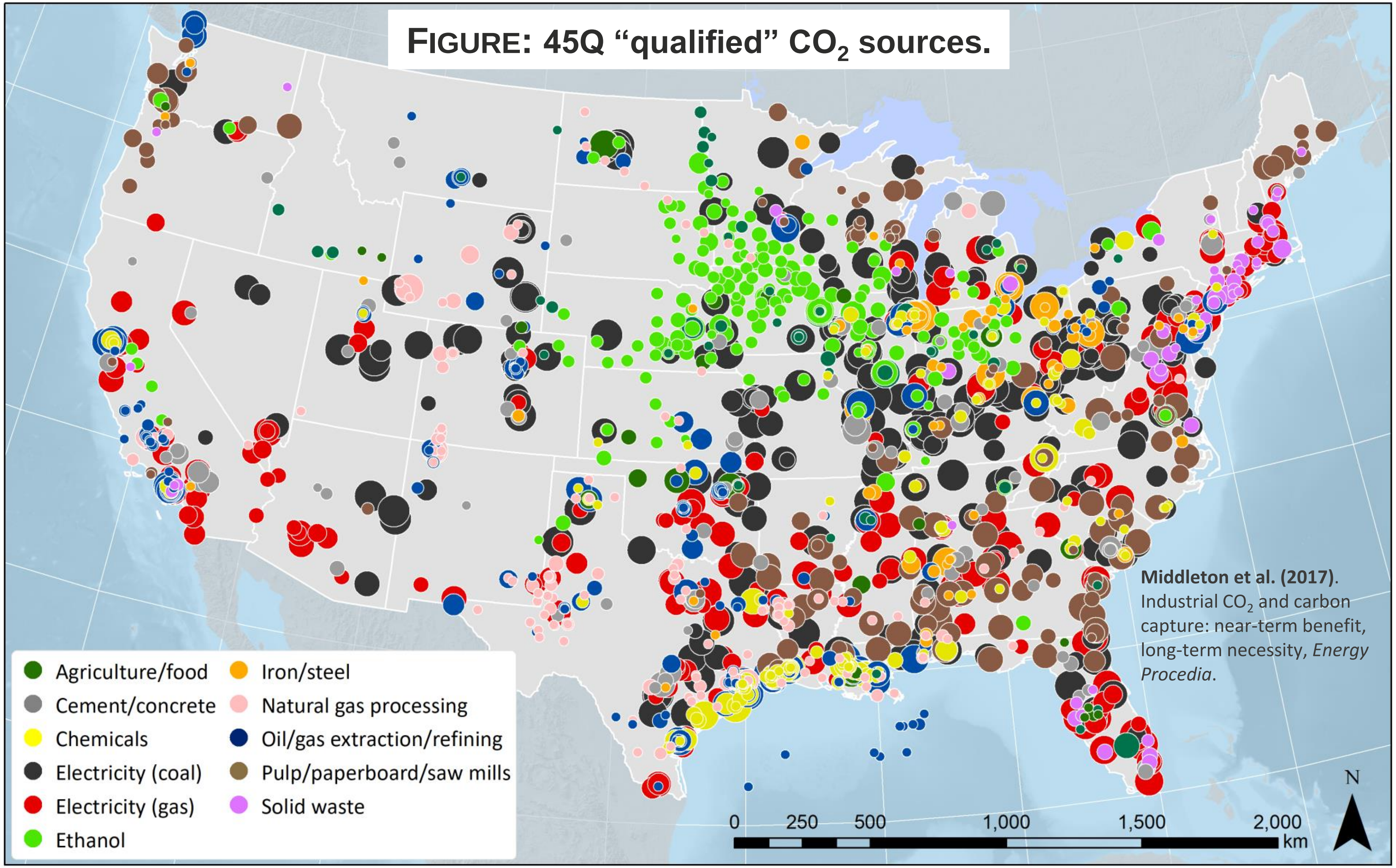
Making BECCS a National Reality

Los Alamos National Laboratory

GIGATONNE ONE: WHY?

Background



Vision

- Gigatonne-scale CCS.
- DOE-FE's CCS vision.

GIGATONNE ONE:

- Approach to understanding how we get to gigatonne-scale CCS in space & time, including multiple pathways.

100s CCS pathways

- **DRIVERS:** CO_2 Incentives, policy, industry targets, oil & CO_2 prices, financing, CCS technologies & economics.

Approach

DOE Investments

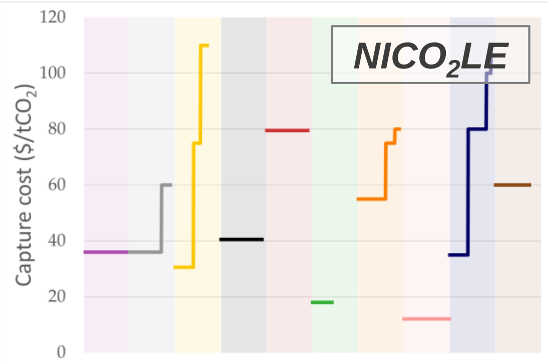
- **SCIENCE, DATA, & TOOLS:** Leverage projects & advances across the CCS value chain.
- **NOW:** understand how CCS might unfold.

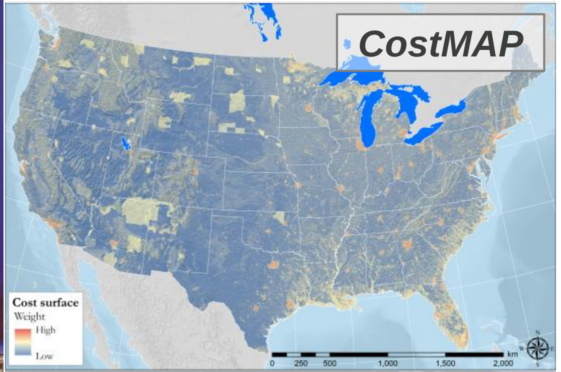
SimCCS

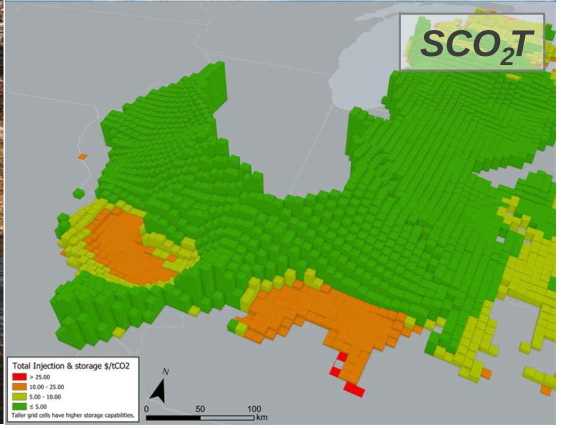
- DOE framework for large-scale CCS decisions (advanced source-sink matching).
- Multi-institutional *Team SimCCS*.

SimCCS tools

1. ***SIMCCS*:** Framework for integrated source-transport-sink decisions.
2. ***SCO_2T*:** Rapid tool that couples physics-based CO_2 injection/storage with economics.
3. ***COSTMAP*:** Pipeline routing and candidate network generation.
4. ***$NICO_2LE$*:** Capturable-CO_2 database, sources broken down by CO_2 streams & economics.







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Challenges

Data challenge

- Building national capture, transport, & storage databases.

Simulation challenge

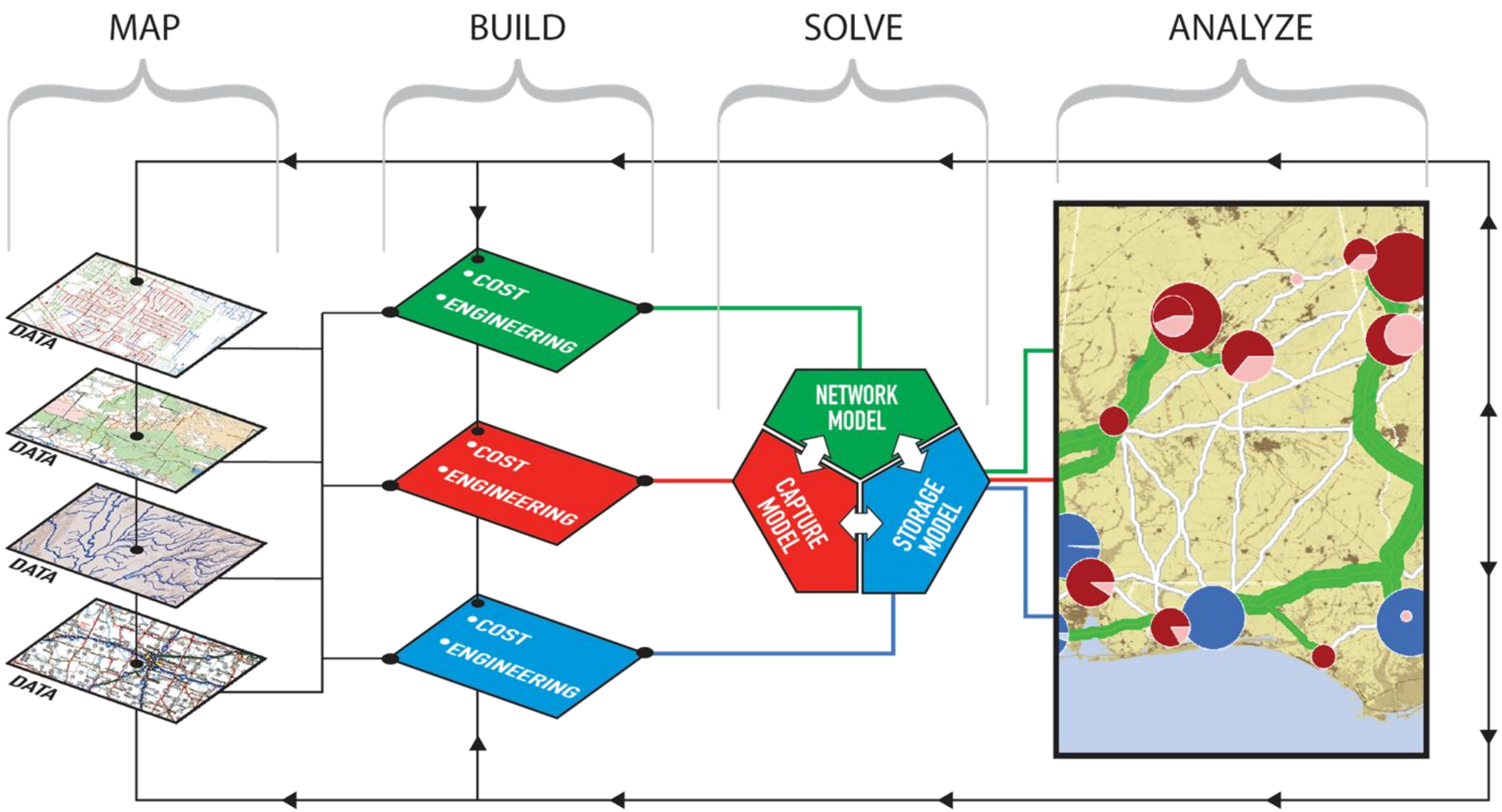
- Realistic national-scale simulations (single run).
- Heuristics, machine learning?

Ensemble challenge

- Uncertainty + pathways = 1000s realizations.
- Paradigm shift.

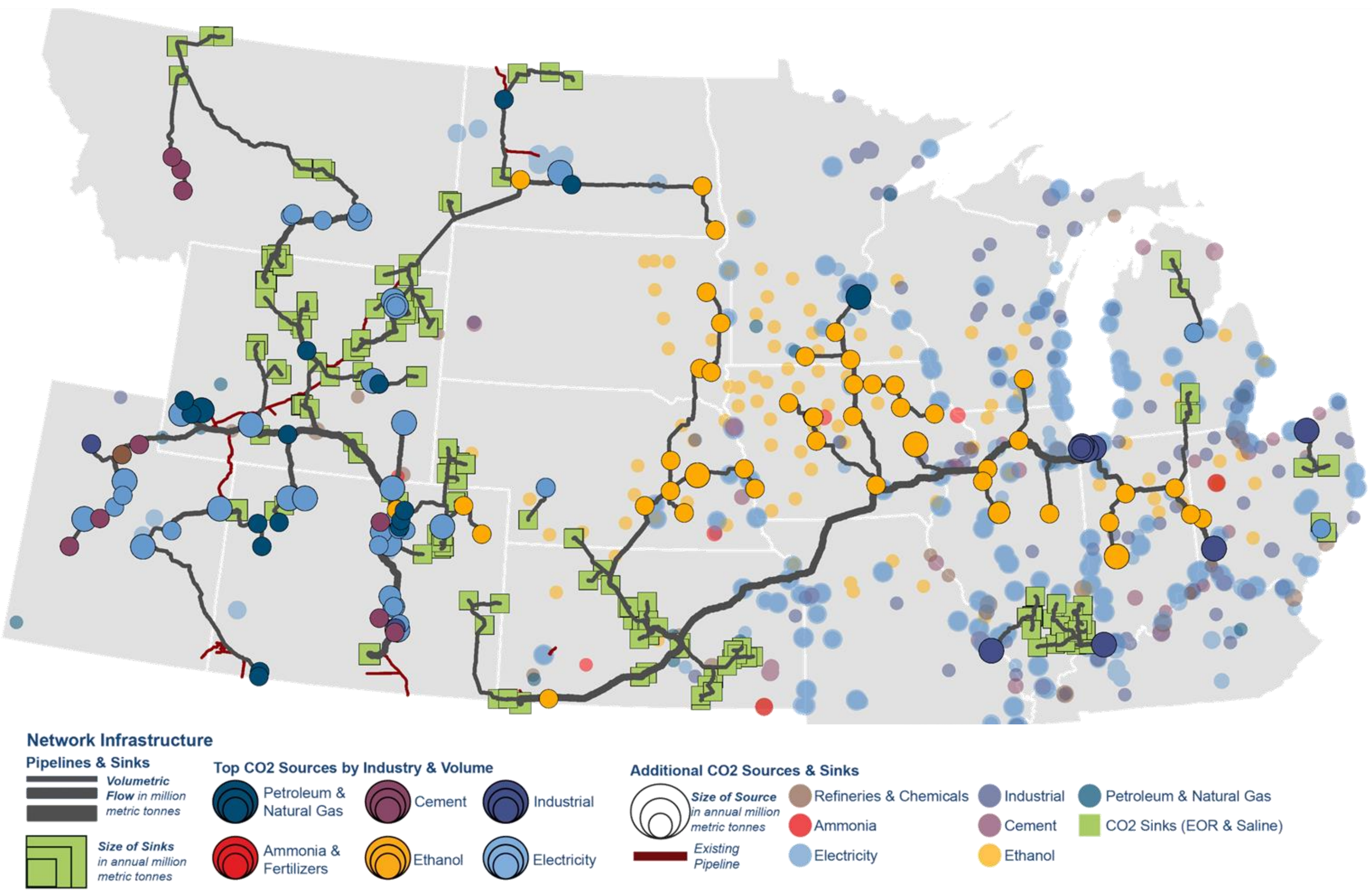
Analysis challenge

- Machine learning to explore 1000s pathways.



GIGATONNE ONE: WHAT?

Scenario Analysis



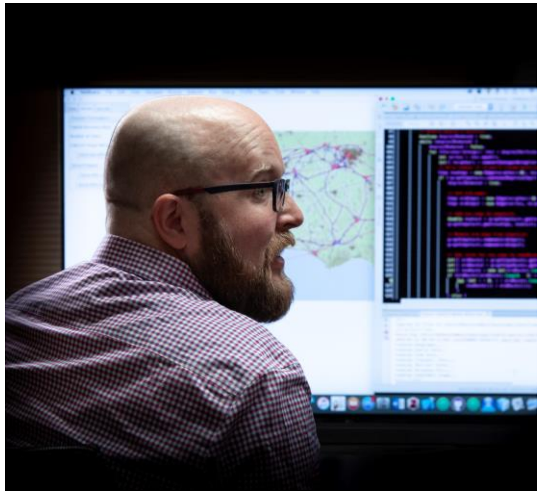
http://www.betterenergy.org/blog/press-release-14-state-work-group-releases-federal-state-recommendations-carbon-capture/

"What if?" scenarios

- Impact of policy & incentives?
- Marginal return (costs, CO_2 amount) from federal investment in expanding industry-funded trunk lines?
- What does coal-dominated Gigatonne One look like?
- LCA-aware CO_2 incentives?
- Change in CCS spatio-temporal deployment given technology price points?
- Massive CCS storage complexes vs. distributed storage (cost, risk, capacity)?

Additional Slides

Team SimCCS



Team

- ~30 participants,16 institutions.

Partners

- **UNIVERSITIES:** Arizona, Indiana, Montana, Ohio, California, Utah, Virginia, West Virginia, Wyoming.
- **INSTITUTIONS:** Battelle, Chinese Academy of Sciences, EPRI, Enhanced Oil Recovery Institute, Great Plains Institute, Kansas Geological Survey, NREL.
- **INDUSTRY:** Advanced Resources International, Archer Daniels Midland, BP, Duke Energy, Glenrock Petroleum, Jupiter Oxygen, Occidental Petroleum, Southern Company.

Scientific visibility

- **PAPERS:** ~30 publications, 1,000+ citations.
- **PEOPLE:** ~100 (published, used, developed, funded).

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Integrated CCS Decisions: *SimCCS*

Why: CCS drivers

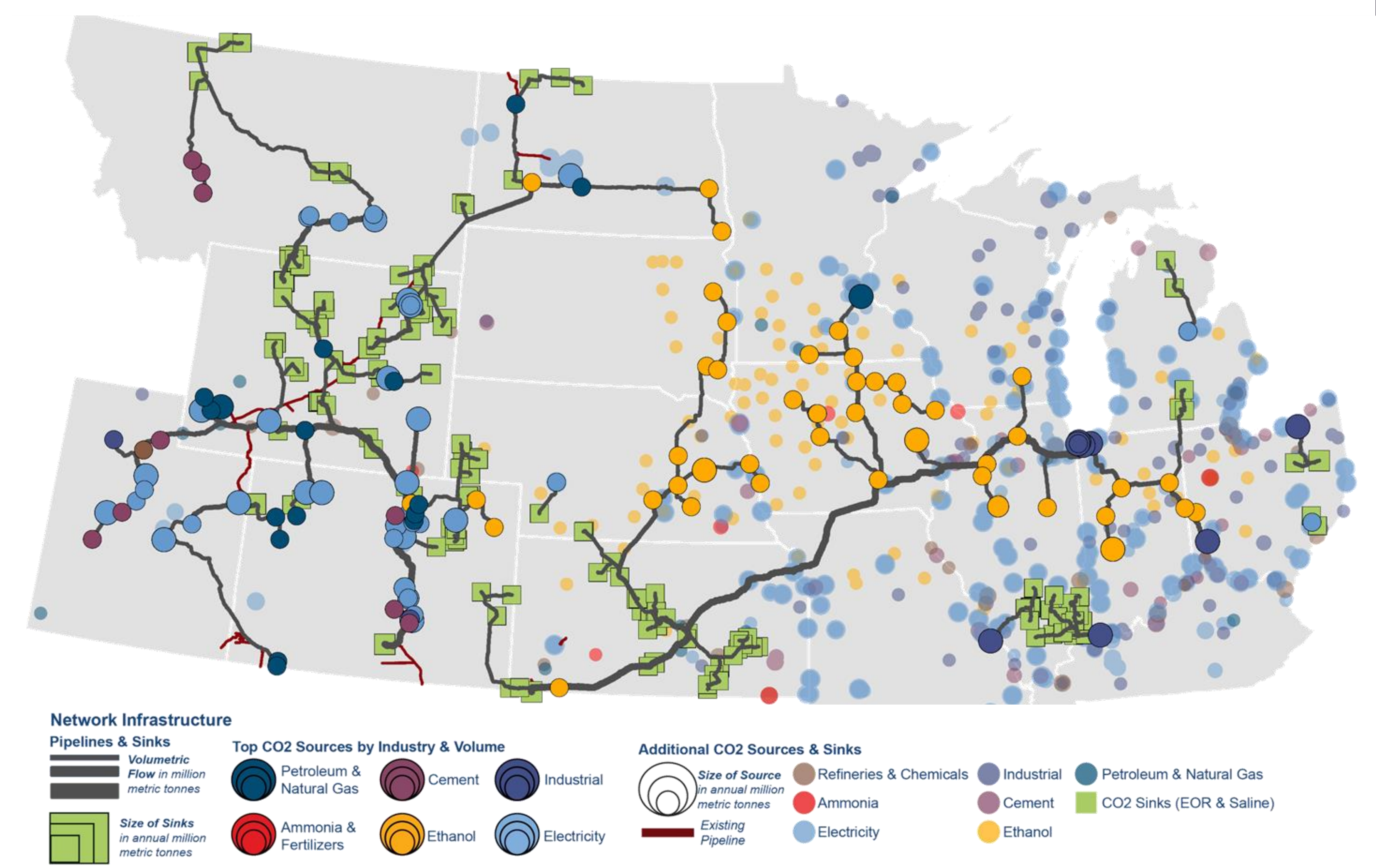
- **GLOBAL**: Climate mitigation.
- **US**: Economic incentives.
- **CHINA**: ETS (CCS in 2030).
- **INDUSTRY**: Carbon footprints.

How: Decision framework

- CCS Infrastructure design.
- Open-source, Java-based, HPC-enabled framework.

What: Scientific visibility

- **PAPERS:** 20+ publications, 1,000+ total citations.
- **People:** ~100 (published, used, developed, funded).
- **R&D 100 AWARDS:** *Software & Services* and *Corporate Social Responsibly* (2019).



Overvie

SimCCS Fra

- Optimization
- Integrated c and storage define econ engineering

CAPTURE

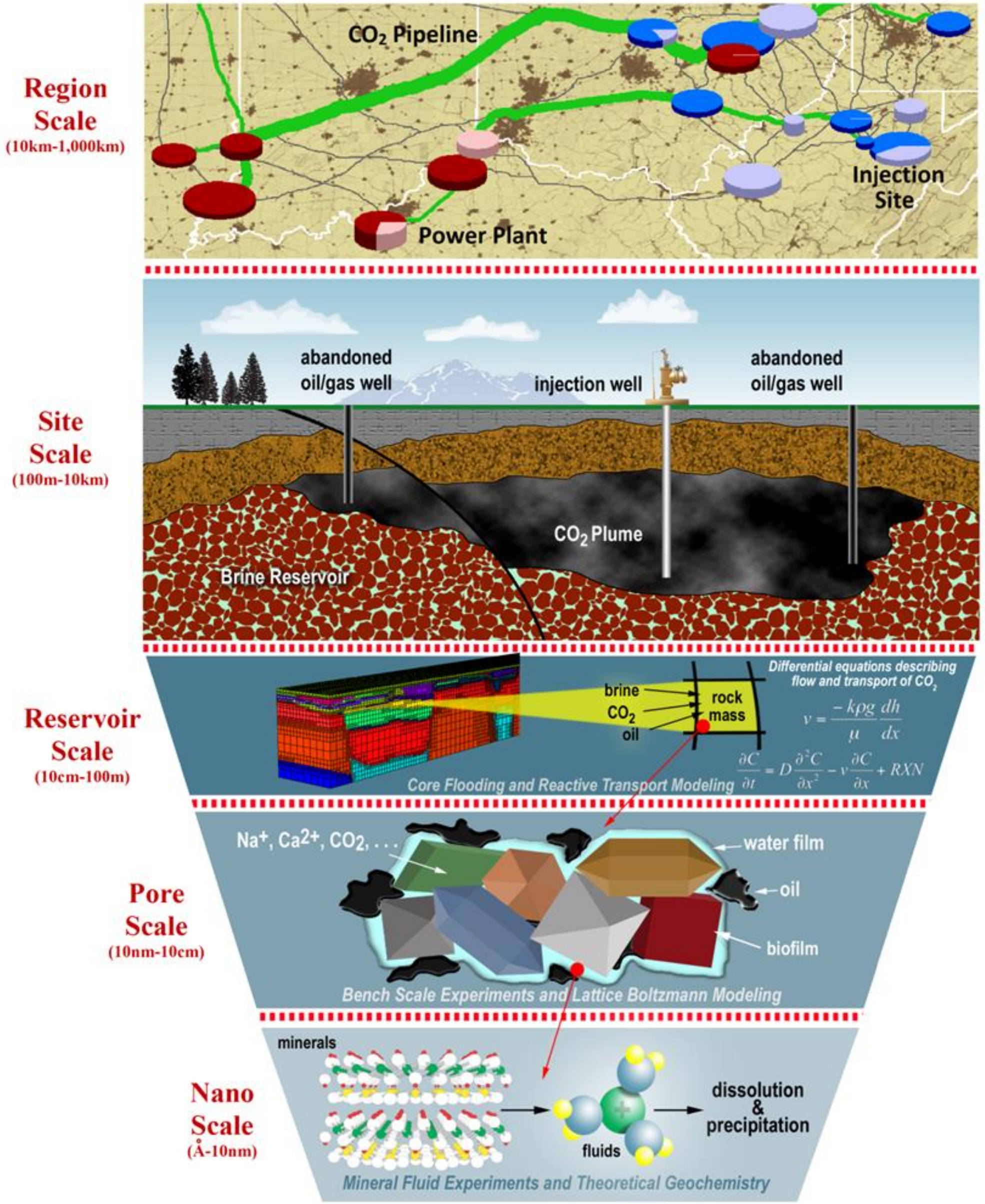
- Literature va
- IECM mode

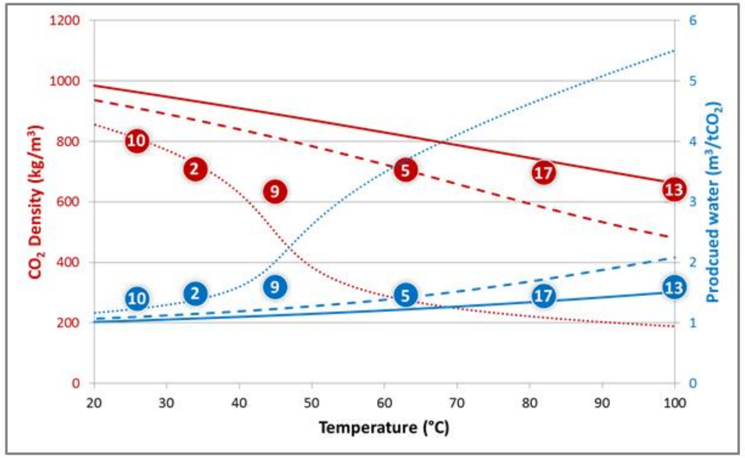
TRANSPORT

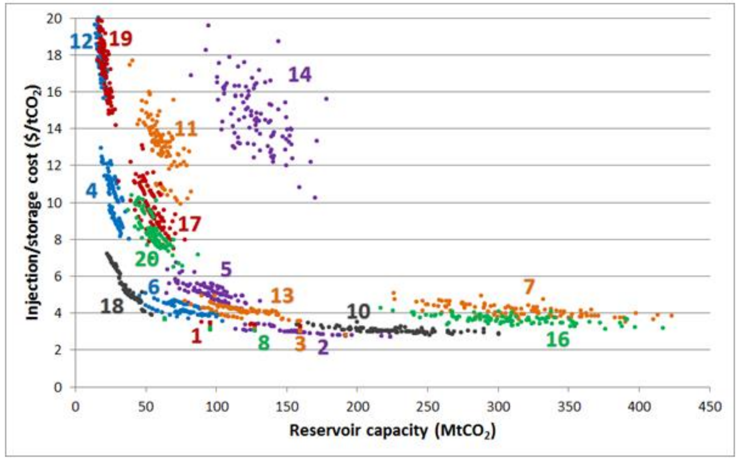
- Cost surface
- Candidate n

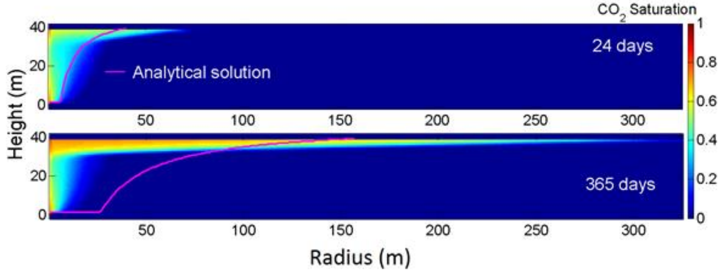
STORAGE

- Reduced or (SCO_2T).
- Custom cos









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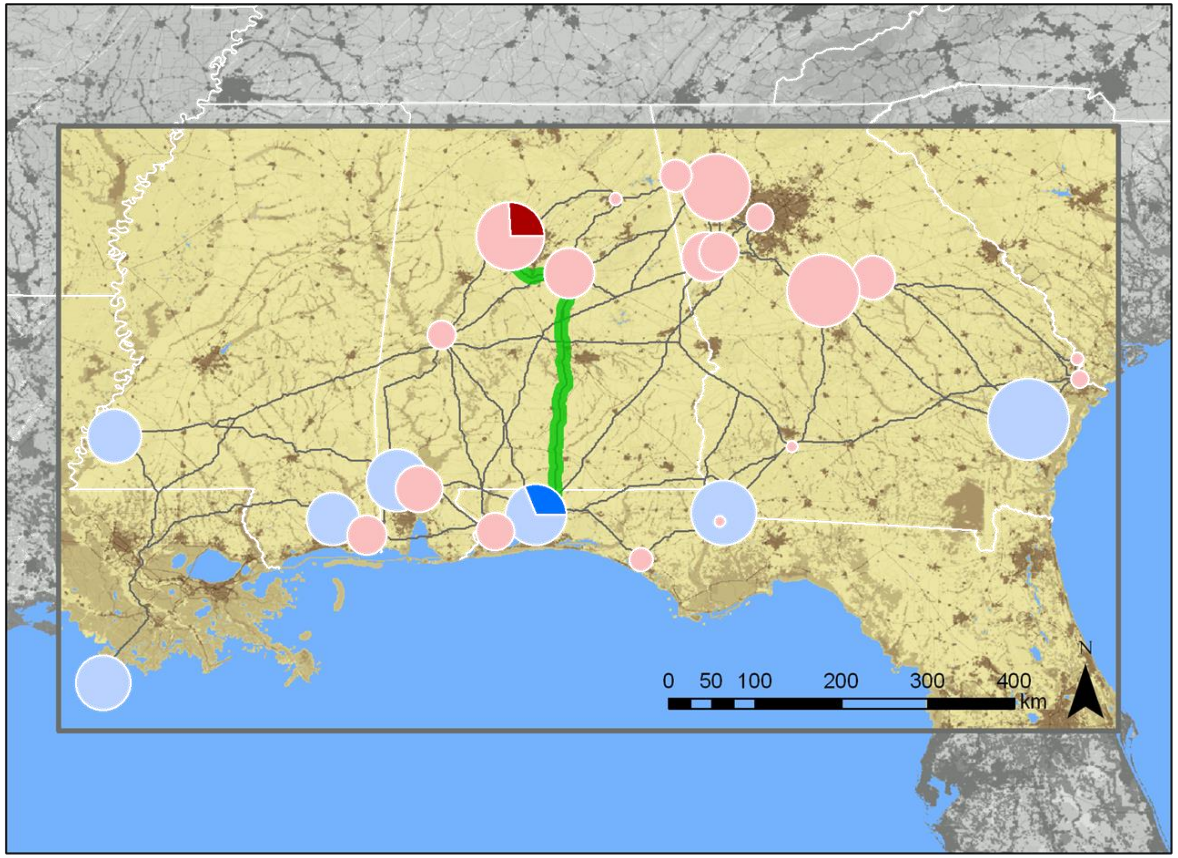
SimCCS: Analysis

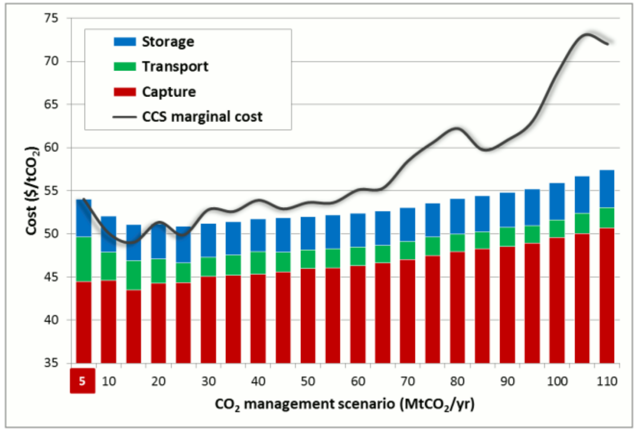
Approach

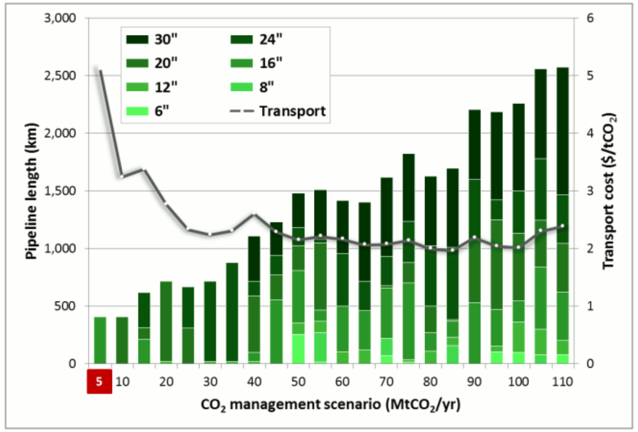
- Cap-and-trade version of *SimCCS* → set CO_2 cap (or target) & minimize costs.
- Inverse: set economic cap and maximize CO_2.

Southern Company

- Ten year business plan and CO_2 emissions strategy.
- 20 coal-fired plants: 156 $MtCO_2$/yr emissions.
- 65 individual boilers→ boiler level accuracy.
- **CAPTURE COSTS:** \$46-102/tCO_2 (plant) & \$41-166/tCO_2 (boiler).
- **STORAGE:** 3.4 $GtCO_2$ in 7 sinks, 113 $MtCO_2$/yr over 30 years.
- **STORAGE COSTS:** \$3.78-8.60/tCO_2.

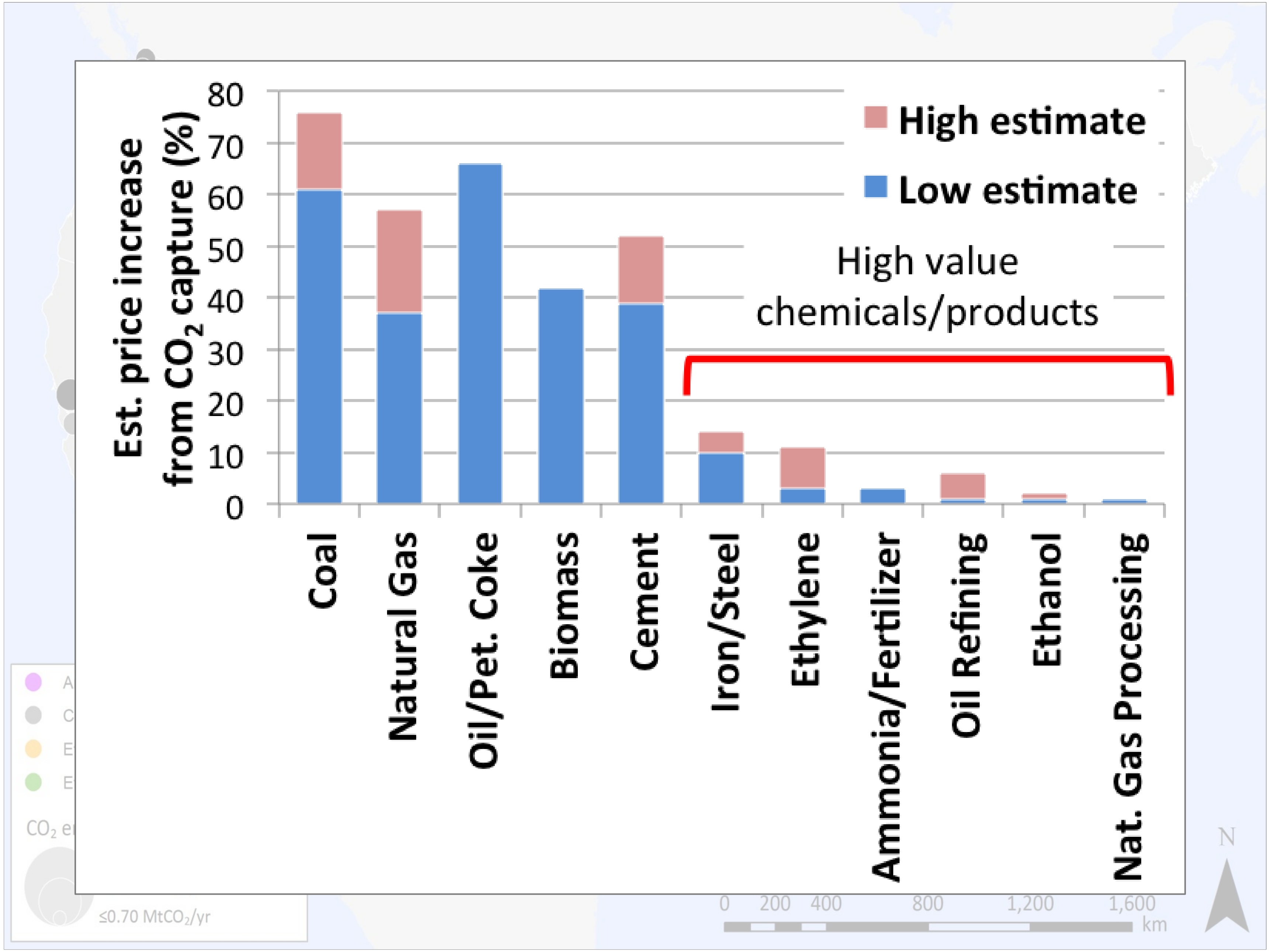






Middleton et al. (2012). The cross-scale science of CO_2 capture and storage: from pore scale to regional scale, *Energy and Environmental Science*, doi.org/10.1039/c2ee03227a.

Capture



Jumpstarting CCS

- Developed the concept of high-value chemicals and products (HVCPs).
- HVCPs: CCS opportunities that can be economically absorbed by supply chains.

Approach

- Life-cycle analysis.
- Infrastructure optimization.
- CCS economics.

Take home message

- First study to identify new way to use industrial CO_2 to jumpstart CCS.

Middleton et al. (2015). Jumpstarting commercial-scale CO_2 capture and storage with ethylene production and enhanced oil recovery in the US Gulf, *Greenhouse Gases: Science and Technology*, doi.org/10.1002/ghg.1490.

Transport

Routing & networks

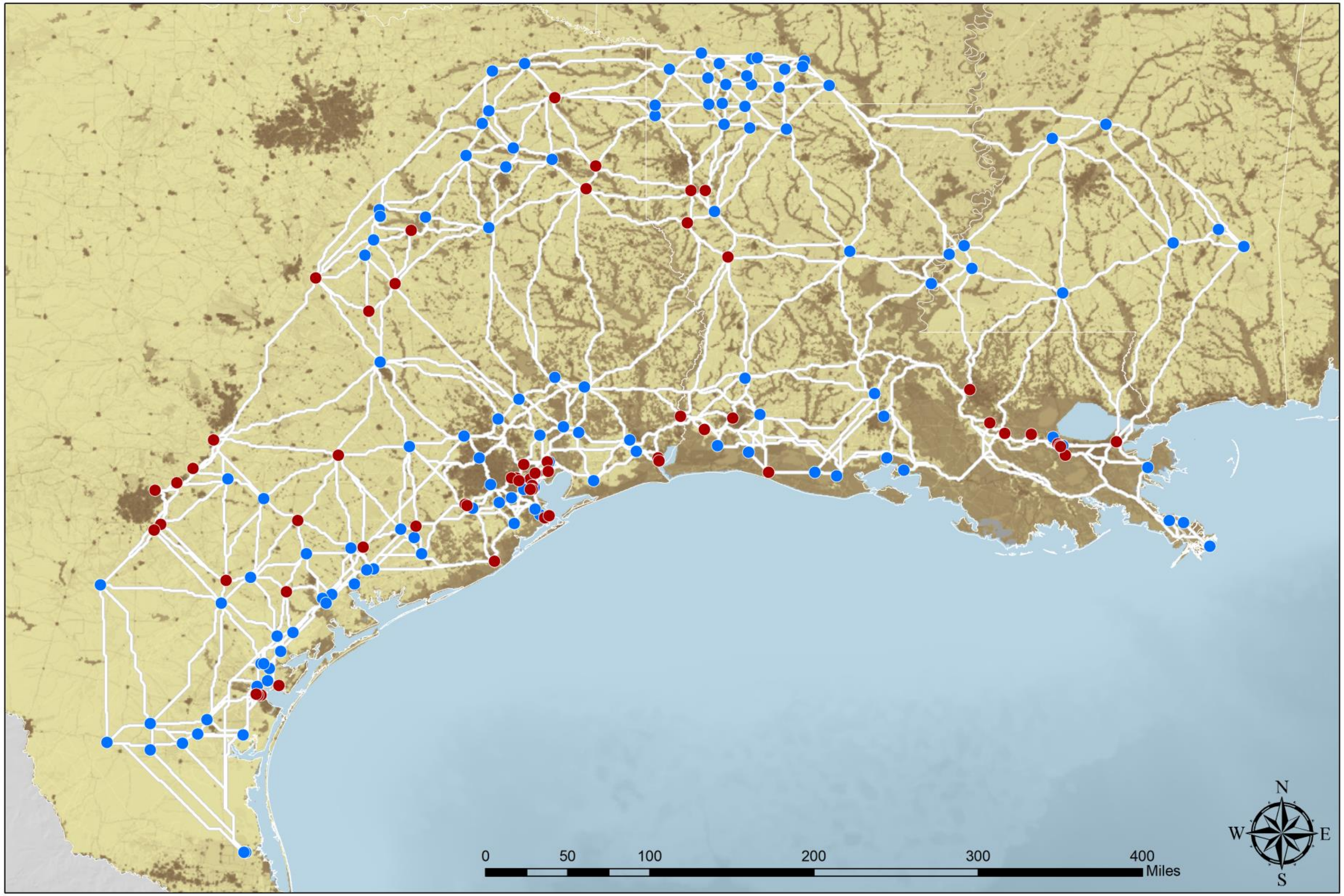
- Most advanced weighted cost surface for pipeline routing.
- Unique approach for converting raster data to vector network.

Approach

- Optimization.
- GIScience.
- Decision analysis.

Take home message

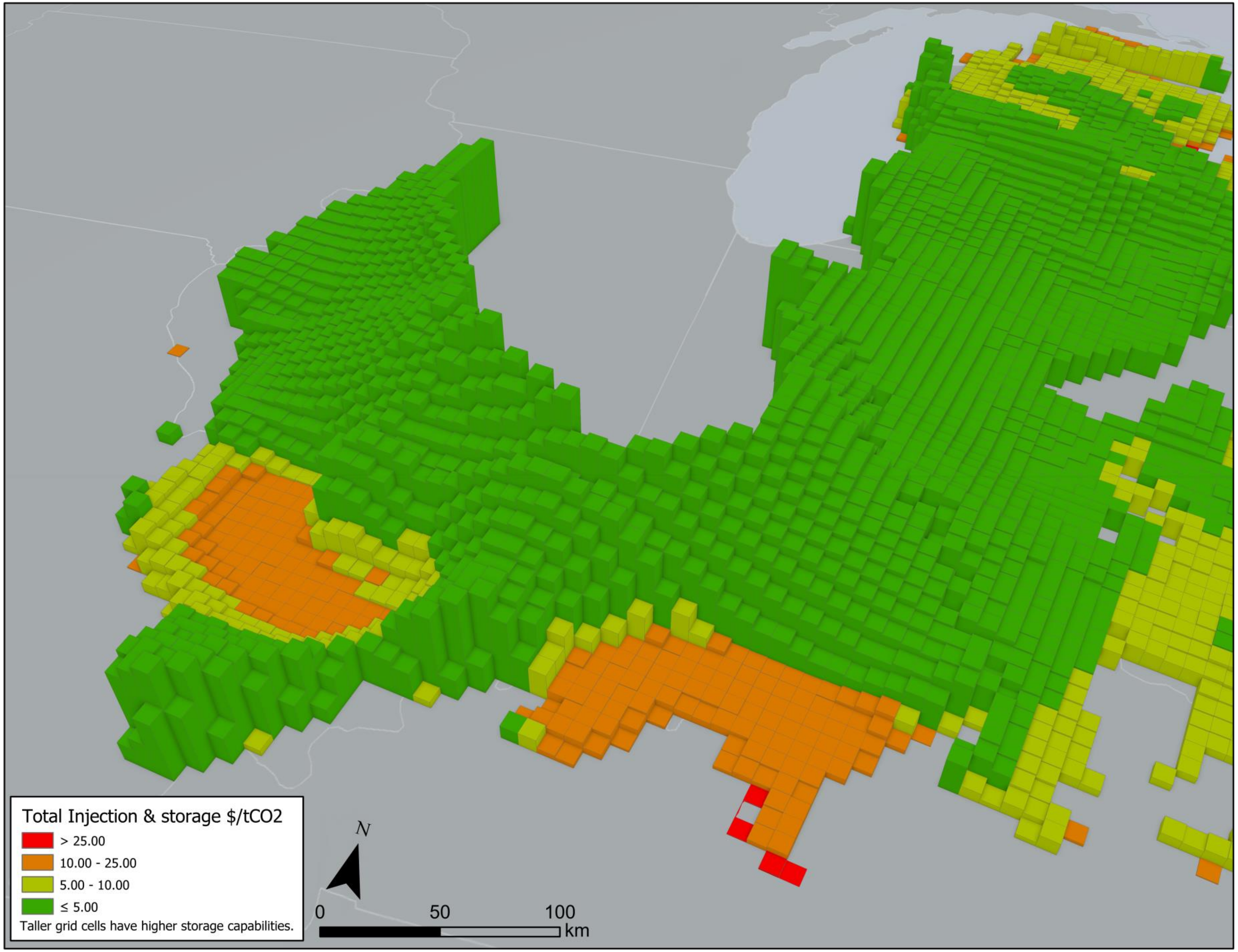
- Transformed pipeline routing and developing potential pipeline networks.



Middleton et al. (2012). Generating candidate networks for optimization: the CO_2 capture and storage optimization problem, *Computers, Environment, and Urban Systems*, doi.org/10.1016/j.compenvurbsys.2011.08.002.

Hoover, Yaw, Middleton et al. (2019). CostMAP: An open-source software package for developing cost surfaces, *International Journal of Geographical Information Science*, doi.org/10.1080/13658816.2019.1675885.

Storage: *SCO_2T*



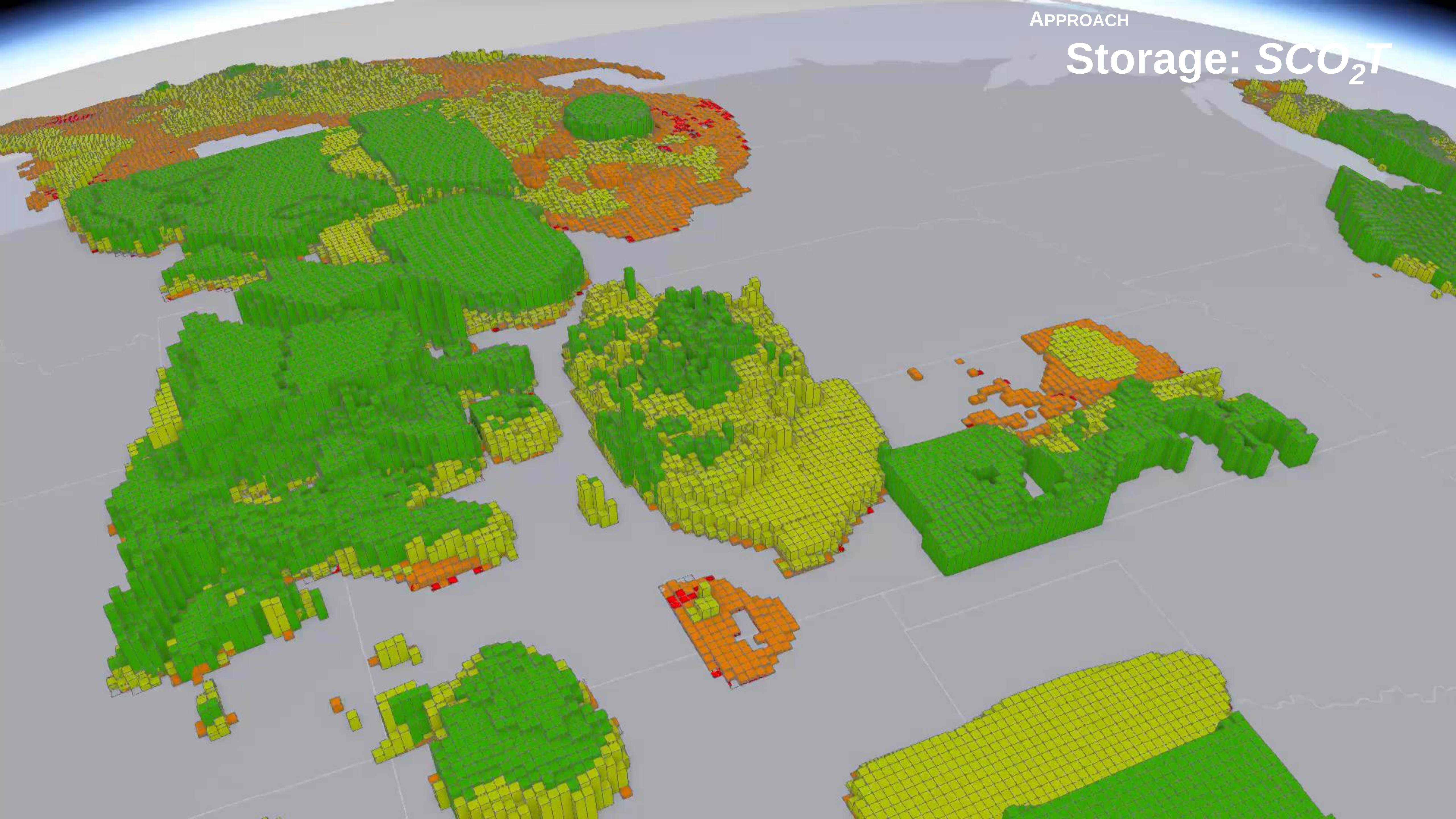
What?

- New tool being developed by *Team SimCCS*.
- New database leveraging NATCARB & USGS.

Unique capability

- Realistic simulated injection (not volumetric analysis).
- Coupled sequestration engineering & economics.
- Replicable & uncertainty.
- Operational tool (e.g., well spacing, 1 $MtCO_2$/yr).
- Impact of brine treatment.
- Nationwide understanding of CO_2 sequestration.

Storage: SCO_2T



SCO_2T

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Goal

- Represent complex physics in a reduced model.

Approach

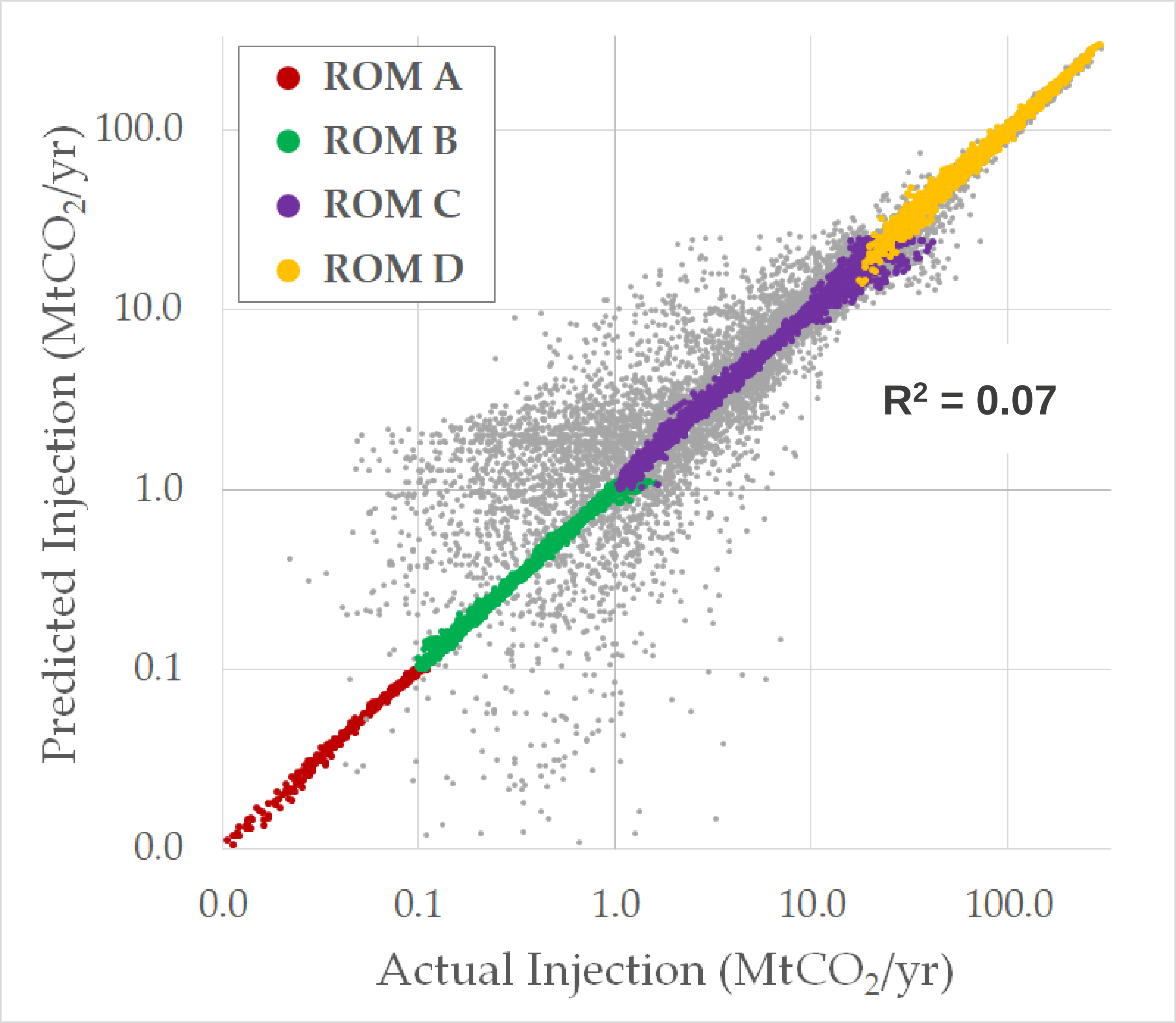
- Use complex, fully-physics simulators to train reduced models: https://fehm.lanl.gov/.

Approach

- 10,000 FEHM runs, ~3 weeks on ~64 cores.
- Vary depth, thickness, perm-eability, porosity, temperature.
- Train multiple ROMs.

Take home message

- Transformational approach to capturing complex physics in rapid-running ROM.



Chen, …, Middleton (2020). Frankenstein's ROMster: Avoiding pitfalls of reduced-order model development, *International Journal of Greenhouse Gas Control*, doi.org/10.1016/j.ijggc.2019.102892.

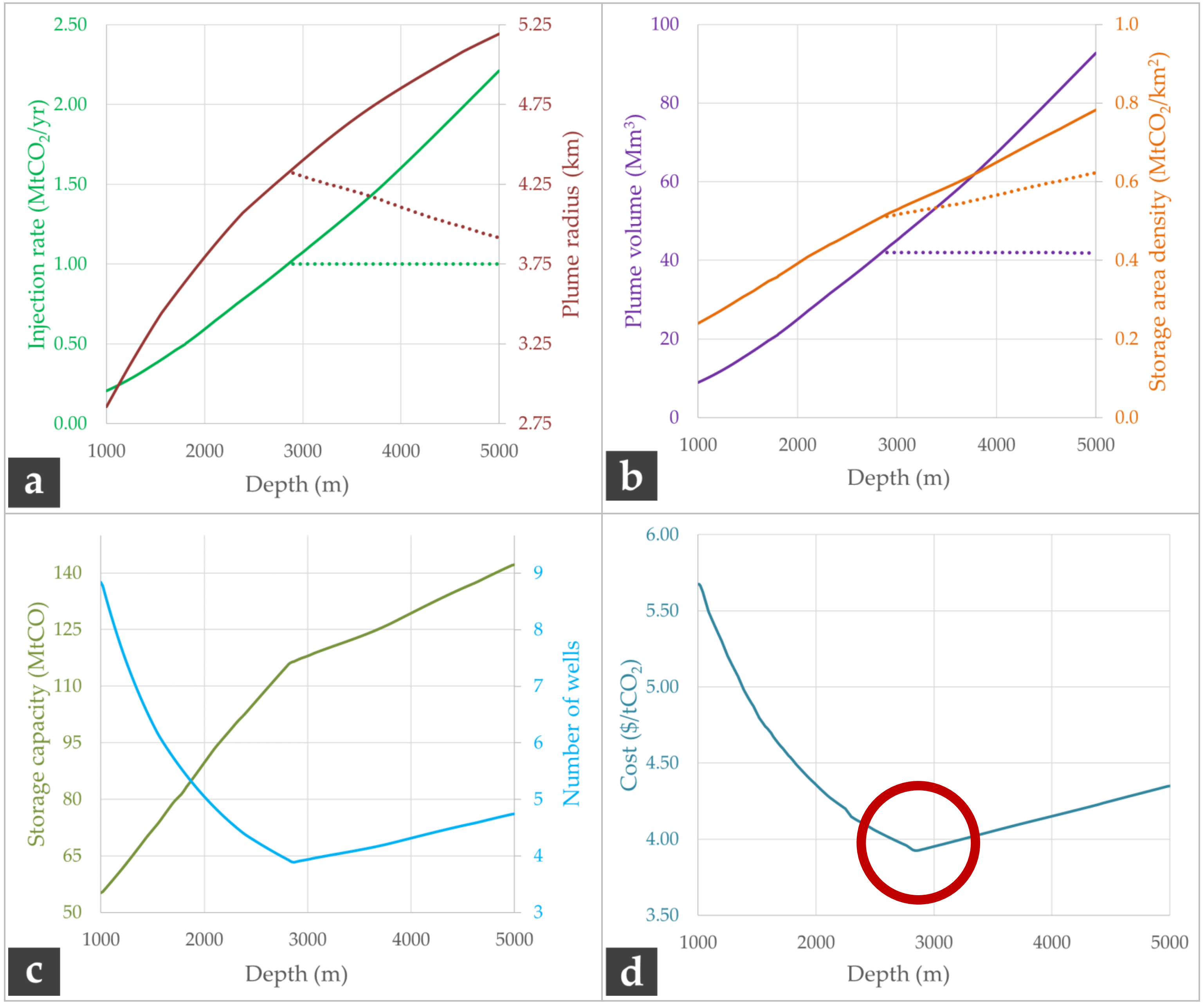
SCO_2T

Sequestration science

- Build ROMster approach into standalone tool.
- Rapidly assess impact of geology on CO_2 injection, plume characteristics, and storage capacity.
- Depth: can increase and decrease sequestration costs.

Take home message

- New & innovative understanding of sequestration science.



Middleton et al. (2020). Great *SCO_2T*! Rapid carbon sequestration science and screening, *Applied Energy* (In Review).

Middleton et al. (2020). Beam me up *SCO_2T*: identifying geologic characteristics and operational decisions to meet global carbon sequestration goals, *Energy and Environmental Science* (In Review).

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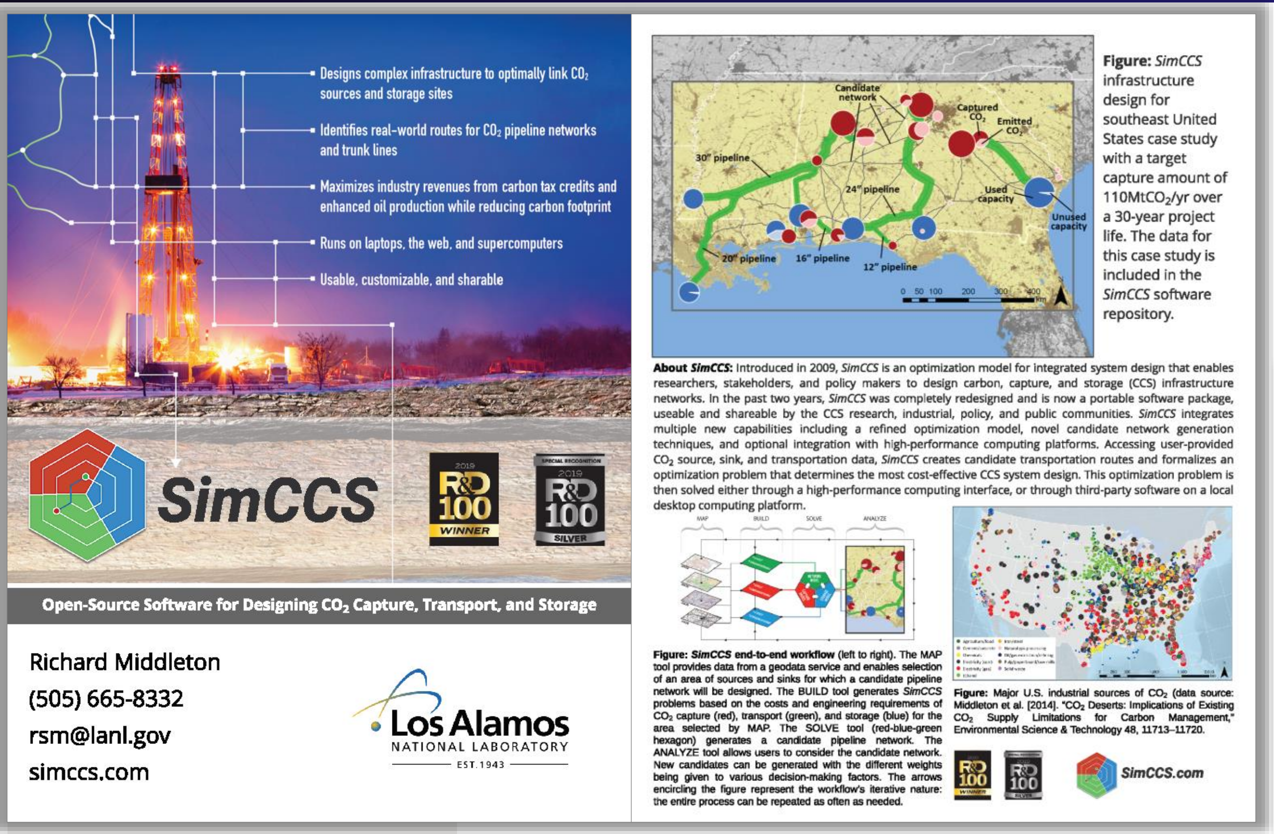
Flyers: *SimCCS* and *SCO_2T*



SimCCS

SCO_2T